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Considering Hydrogen Fuel Cells Powertrain as Power Generation Plant

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Abstract

Every day more than 90% of vehicles are parked, even during peak traffic hours. In this situation, the vehicle power generation system hydrogen fuel cell based (H2FC Powertrain), if properly equipped, could become a new power generation source, supplying electricity to homes and to the grid like a new type of distributed generation: Vehicle-to-Grid (V2G). The V2G concept is well known but, in the paper, the H2FC Powertrain is considered as power generation plant and, based only on public data, it is compared with the traditional power generation technologies. The results are surprising. Using only tested H2FC Powertrain data (DOE 2009, referred to projected high volume production) we found that the cost generating baseload electricity would be in a range of USD 179,2 - 196,7 for MWh. Comparing this cost range with the levelised costs of electricity (LCOE) published in the most recent studies, H2FC Powertrain generation would be at lower cost than wind offshore, solar thermal and solar photovoltaic. However, using the 2015 DOE data target the of H2FC Powertrain, electricity production cost range moves to USD 106,6 - 156,6 for MWh, and, in most of the context, it appears competitive with all the power generation technologies.

Keywords: Fuel Cell Vehicle, Hydrogen, Vehicle-to-Grid, Power Generation Plant, LCOE.

1. The Vehicle-to-Grid Concept

Currently more than 90% of vehicles are parked, even during peak traffic hours. In this situation the vehicle power generation system fuel cell based (H2FC powertrain), if properly equipped, could become a new power generation source, supplying electricity to homes and to the grid like a new type of distributed generation: Vehicle-to-Grid (V2G).
Academics, public and private operators well know the V2G concept [1, 2, and 3]. V2G could be realized indifferently with Electric Vehicles (EV) and Fuel Cell Vehicles (FCV), but only in the case of FCV, we are in presence of a real new power generation capacity GHG emission free: the H2FC powertrains.

FCV in a V2G mode may profitably provide power to the grid when they are parked and connected to an electrical outlet. In this perspective, literature analyzed also the economic aspects [4, 5]. FCV have significant potential revenue streams from V2G, on peak power production, but it is possible to obtain higher return offering a series of high-value ancillary services to the grid. If well implemented, the FCV potential revenue streams from V2G could help to reduce the initial high FCV costs, reducing in this way also the amount of public subsidy and incentives that all the current introduction scenarios needed in order to support the introduction of this low-carbon transport technology by 2020.

If FCV, properly equipped and parked in V2G mode, become a new power generation source supplying electricity to homes and to the grid, it could be useful to begin to analyze the H2FC powertrain relevance in the power generation sector.

In this perspective, in the paper the H2FC powertrain is considered as power generation plant and, based only on public data, the cost of electricity production is compared with the generation costs of the traditional power generation technologies in a simple and preliminary analysis.

2. Levelized Cost of Electricity (LCOE) Generation

2.1 Definition

According to OECD/IEA-NEA (IEA) [6] the levelized costs of generating electricity (LCOE) approach is a financial model used for the analysis of generation costs.
Focus of the estimated average LCOE is the entire operating life of the power plants for a given technology. In this model, different cost components are taken into account: capital costs, fuel costs, operations and maintenance (O&M) costs. These costs are an average over the life of a project and for a specific technology, based on a specific and particular set of assumptions.
Under LCOE financial model, costs cash-flow is discounted to the present (date of commissioning) using assumed specific discount rates. The resultant LCOE values, one for each generation option, are the main driver for choice technology. The unit of measure typically used for the LCOE is USD/MWh.

Investment costs are probably the most important element in any investment decision. They vary greatly from technology to technology, from time to time and from country to country. "Overnight cost" is a common unit of measure of power investments. The Overnight cost is the cost of a construction project if no interest was incurred during construction, as if the project was completed "overnight." The unit of measure typically used for the Overnight cost is USD/kW.

In a traditional context of integrated monopoly, regulated electricity prices charged to consumers reflected long-term average cost of producing electricity. In the competitive generation markets, relationship between average costs and prices is no longer obvious. Prices are set by the marginal cost of the last dispatched technology and once a power plant is built, investment is considered "sunk costs".

The notion of LCOE generation is a handy tool for comparing the unit costs of different power generation technologies but it need to be aware of the limitations of the data.

2.2 Overview of Recent LCOE Analyses

Recently, different authoritative institutions released analysis regarding the future LCOE generation:

- in November 2008 the European Commission (EC) [7],
- in January 2010 the U.S. Energy Information Administration (EIA) [8], and
- in March 2010, the OECD/IEA-NEA (IEA) [6].

Each of these analyses adopts little difference with regard to LCOE definition; to elements included in LCOE formula (only EIA [8] included "Transmission Investment"); to assumptions adopted.
With regard of assumptions adopted, we note many differences. Year of reference is 2015 for IEA [6], 2020 and 2030 for EC [7], and 2016 for EIA [8]. Discount rate is 5% and 10% for IEA [6], 10% for EC [7], and an annual WACC in a nominal 10%-12% range for EIA [8]. Currency is EUR for EC [7], USD for IEA [6] and EIA [8]. The geographic area is world for IEA [6], EU27 for EC [7], U.S. for EIA [8]. Cost of fuel and price of electricity assumptions are different.

The Fuel Cell technology is included in different way in these analyses. In Reference [7] (EC) the Fuel Cell technology is not considered. In Reference [8] (EIA) Fuel Cell is not included in the final table published in the web but is considered in the Assumption Report [9] and Spreadsheet [10]. In Reference [6] (IEA) the Fuel Cell technology is considered and included in the analysis.

In detail, the *EC analysis* [7], synthesized in Table 1 (in next page), includes two fuel price scenarios: *Moderate* (oil barrel at 54.5 USD in 2007, 61 USD in 2020 and 63 USD in 2030) and *High* (oil barrel at 54.5 USD in 2007, 100 USD in 2020 and 119 USD in 2030). In this analysis, carbon costs are were considered only for the projected LCOE in 2020 and 2030. It was assumed that each ton of CO2 directly emitted from the facility was charged with 41 EUR/tCO2 in 2020 and 47 EUR in 2030.

With regard to the *U.S. EIA analysis* [8], summarized in Table 2 (in next page), it includes in the Total System Levelized Cost also the Transmission Investment. A 3-percentage point increase in the cost of capital is added when evaluating investments in GHG intensive technologies like coal-fired power plants without carbon control and sequestration (CCS) and coal-to-liquids plants. The 3-percentage point adjustment has, in levelized cost terms, an impact similar to that of a 15 USD/tCO_2 emissions fee applied to investment in a new coal plant without CCS.

Table 1 - Energy Technologies for Power Generation: Reference [7], European Commission (EC) 2008

Energy Source	Power Generation Technology	Overnight Cost (EUR/kW) Capital Investment Cost Status of Art 2007		Levelized Production Cost of Electricity (EUR/MWh) Moderate Fuel Price Scenario	Projection for:		High Fuel Price Scenario	Projection for:	
		Ref.	Range	2007	2020	2030	2007	2020	2030
Coal	Pulverised Coal Combustion (PCC)	1265	1000 - 1440	40 - 50	65 - 80	65 - 80	40 - 55	**80 - 95**	85 - 100
	PCC with CCS	2250	1700 - 2700	na	80 - 105	75 - 100	na	**100 - 125**	100 - 120
	Circulating Fluidised Bed Combustion (CFBC)	1400	1250 - 1500	45 - 55	75 - 85	75 - 85	50 - 60	**95 - 105**	95 - 105
	Integrated Gasification Combined Cycle (IGCC)	1550	1400 - 1650	45 - 55	70 - 80	70 - 80	50 - 60	**85 - 95**	85 - 95
	IGCC with CCS	2100	1700 - 2400	na	75 - 90	65 - 85	na	**95 - 110**	90 - 105
Gas	Open Cycle Gas Turbine (GT)	310	200 - 400	65 - 75	90 - 95	90 - 100	80 - 90	**145 - 155**	160 - 165
	Combined Cycle Gas Turbine (CCGT)	635	470 - 730	50 - 60	65 - 75	70 - 80	60 - 70	**105 - 115**	115 - 125
	CCGT with CCS	1200	1000 - 1440	na	85 - 95	80 - 90	na	**130 - 140**	140 - 150
Oil	Internal Combustion Diesel Engine	800	550 - 1350	100 - 125	140 - 165	140 - 160	125 - 145	**200 - 220**	230 - 250
	Combined Cycle Oil-fired Turbine	1000	900 - 1100	95 - 105	125 - 135	125 - 135	115 - 125	**175 - 185**	200 - 205
Nuclear	Nuclear Fission	2680	1970 - 3380	50 - 85	45 - 80	45 - 80	55 - 90	**55 - 90**	55 - 85
Wind	On-shore	1140	1000- 1370	75 - 110	55 - 90	50 - 85	75 - 110	**55 - 90**	50 - 85
	Off-shore	2000	1750 - 2750	85 - 140	65 - 115	50 - 95	85 - 140	**65 - 115**	50 - 95
Solar	Photovoltaic	4700	4100 - 6900	520 - 880	270 - 460	170 - 300	520 - 880	**270 - 460**	170 - 300
	Concentrating Solar Power	5000	4100 - 6000	170 - 250	110 - 160	100 - 140	170 - 250	**130 - 180**	120 - 160
Biomass	Solid Biomass	3800	2090 - 5080	80 - 195	85 - 200	85 - 205	80 - 195	**90 - 215**	95 - 220
	Biogas	3140	2960 - 5790	55 - 215	50 - 200	50 - 190	55 - 215	**50 - 200**	50 - 190
Hydro	Large	1350 - 2510	900 - 4500	35 - 145	30 - 140	30 - 130	35 - 145	**30 - 140**	30 - 130
	Small	2900 - 4500	2000 - 6600	60 - 185	55 - 160	50 - 145	60 - 185	**55 - 160**	50 - 145

Table 2 - Estimated Levelized Cost and Other Data of New U.S. Generation Plants Entering Service in 2016: Reference [8], U.S. Energy Information Administration (EIA) 2010

Plant Type	Plant Size (MW)	Overnight Cost in 2009 (USD/kW) Overnight Cost (2008USD/kW)	Project Contingency Factor	Technological Optimism Factor	Final Overnight Cost (2008USD/kW)	Levelized Production Cost of Electricity (USD/MWh) Levelized Capital Costs	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System Levelized Cost
Conventional Coal	600	2078	1,07	1,00	2223	69,2	3,8	23,9	3,6	**100,5**
Advanced Coal	550	2401	1,07	1,00	2569	81,2	5,3	20,4	3,6	**110,5**
Advanced Coal with CCS	380	3427	1,07	1,03	3776	92,6	6,3	26,4	3,9	**129,2**
Conventional Gas Combined Cycle	250	937	1,05	1,00	984	22,9	1,7	54,9	3,6	**83,1**
Advanced Gas Combined Cycle	400	897	1,08	1,00	968	22,4	1,6	51,7	3,6	**79,3**
Advanced Gas Combined Cycle with CCS	400	1720	1,08	1,04	1932	43,8	2,7	63,0	3,8	**113,3**
Conventional Combustion Gas Turbine	160	653	1,05	1,00	685	41,1	4,7	82,9	10,8	**139,5**
Advanced Combustion Gas Turbine	230	617	1,05	1,00	648	38,5	4,1	70,0	10,8	**123,4**
Advanced Nuclear	1350	3308	1,10	1,05	3820	94,9	11,7	9,4	3,0	**119,0**
Fuel Cells (Molten Carbonate)	10	4744	1,05	1,10	5478					
Wind	50	1837	1,07	1,00	1966	130,5	10,4		8,4	**149,3**
Wind - Offshore	100	3492	1,10	1,02	3937	159,9	23,8		7,4	**191,1**
Solar PV	5	5879	1,05	1,00	6171	376,8	6,4		13,0	**396,2**
Solar Thermal	100	4798	1,07	1,00	5132	224,4	21,8		10,4	**256,6**
Geothermal	50	1666	1,05	1,00	1749	88,0	22,9		4,8	**115,7**
Biomass	80	3414	1,07	1,05	3849	73,3	9,1	24,9	3,8	**111,1**
Hydro	500	2084	1,10	1,00	2291	103,7	3,5	7,1	5,7	**120,0**

The *OECD/IEA-NEA analysis* [6] presents detailed data on electricity generating costs for 190 power plants in 17 OECD countries and 4 non-OECD (Brazil, China, Russia and South Africa).
Table 3 (in next page) is our re-elaboration of these plants data (with exclusion of the 20 CHP plants data). The LCOE calculated are at plant-level costs and do not include transmission and distribution costs. This analysis assumes a carbon price of USD 30 per ton of CO_2 emitted and includes two discount rate scenarios: 5% and 10%.

2.3 Main Conclusion from LCOE Overview

At the end of this LCOE analyses overview, it is evident a wide dispersion of data and there is no technology that has a clear overall advantage globally or even regionally.
Results are particularly sensible to the fuel and electricity price assumptions. Discount rate level is another key element. Results vary from analysis to analysis, from country to country, and even within the same region, there are significant variations in the cost for the same technologies. Country-specific

Table 3 - Our Re-Elaboration of LCOE and Other Data of New OECD Generation Plants Entering Service in 2015. Reference [6], OECD/IEA-NEA 2010 Plants Data

Plant Type	Plant Size (MW)	Overnight Cost (USD/kW)	Levelized Production Cost of Electricity (USD/MWh)	
			LCOE 5%	LCOE 10%
Coal	300 - 1312	807 - 4671	53,97 - 120,01	**67,34 - 141,64**
Coal with CC(S)	255 - 970	3223 - 6268	56,62 - 102,59	**82,42 - 152,27**
Gas Turbine	150 - 230	520 - 649	91,48 - 118,77	**95,08 - 122,61**
CCGT	395 - 1600	635 -1622	67,03 - 105,14	**73,36 - 119,53**
CCGT with CC(S)	387 - 400	1928 - 2611	91,90 - 98,21	**104,19 - 117,90**
Oil Engine	83	1817	104,63	**119,03**
Nuclear	954 - 1650	1556 - 5863	29,05 - 78,24	**42,09 - 136,50**
Fuel Cells	10	5459	181,17	**213,14**
Wind	2 - 150	1912 - 3716	48,39 - 162,90	**70,47 - 234,32**
Wind - Offshore	3,6 - 400	3824 - 6083	101,02 - 188,21	**146,44 - 260,80**
Solar PV	0,03 - 10	3267 - 7381	215,45 - 626,87	**332,78 - 934,63**
Solar Thermal	1 - 100	4347 - 5255	136,16 - 211,18	**202,45 - 323,71**
Geothermal	5 - 500	1752 -12887	32,48 - 164,78	**46,76 - 269,93**
Biomass	11 - 80	3830 - 7431	53,77 - 160,50	**80,82 -197,04**
Hydro	0,3 - 1000	2703 - 19330	34,74 - 231,63	**70,89 - 459,32**

circumstances determine the LCOE and it is very difficult to generalize on costs.
Analyzing data calculated with different discount rate (when available), it appears clear that all the capital-intensive technologies are advantaged with low discount rates. At higher rates, coal and gas (without CCS) will be more competitive.

3. Considering Hydrogen Fuel Cells Powertrain as Power Generation Plant

3.1 Fuel Cells

A Fuel Cell is a device that uses a fuel and oxygen to create electricity by an electrochemical process, without combustion. Fuel Cells are classified primarily by the kind of electrolyte they employ: *Phosphoric Acid Fuel Cells* (PAFC), *Alkaline Fuel Cells* (AFC), *Molten Carbonate Fuel Cells* (MCFC), *Solid Oxide Fuel Cells* (SOFC), *Direct Methanol Fuel Cells* (DMFC) and *Polymer Electrolyte Membrane* (PEM) *Fuel Cells* (also called *Proton Exchange Membrane Fuel Cells*).
Today Fuel Cells are present in a wide range of prototype and products: portable applications, micro CHP system, recreation products, vehicles, niche and professional application, military items.

In presence of a so this wide context of application, why consider the Hydrogen Fuel Cell (PEM) Powertrain (H2FC Powertrain) as Power Generation Plant? Because, according with Reference [11], if the current U.S. Hydrogen and Fuel Cell Vehicle program will be able to met all the 2015 technological targets, in the subsequent year, the high volume associates with the H2FC vehicles mass production (over 500.000 unit sold per year) will permit to reduce dramatically the Fuel Cell system manufacturing costs. In this way, the H2FC Powertrain will be so cost competitive to be useful adopted also for stationary power generation application [12].
In this high projected volume production context, adopting the H2FC Powertrain as power generation plants, the investments cost component in the LCOE value will be at one of the lowest level compared with current technologies.

3.2 The H2FC Powertrains LCOE

In order to consider a H2FC Powertrain as Power Generation Plant it is necessary to calculate its specific LCOE and, for this reason, we need some H2FC Powertrains data: the system cost (Overnight and Levelized); the expected system lifetime; the system efficiency and the fuel cost (hydrogen cost).

3.2.1 The 2009 Public Data

Based on projected high volume public data (References [13 and 14]), we find these values for year 2009: Overnight cost 61 USD/kW, Levelized Capital cost 24,2 - 24,4 USD/MWh, Lifetime 2500 - 2521 hours, 53%-59% System Efficiency, and 3 UDS/GGE Hydrogen cost.
With regard to Hydrogen cost, Reference [14] presented, for on-site natural gas reformation, an Hydrogen cost at station in a range of 7,7 – 10,3 USD/GGE. This range appears completely out of target but it is a real early market data. In the same context, Reference [14] observe that, a DOE independent panels [15] confirmed at 500 replicate stations/year with 1500 kg/day distributed natural gas reformation, an Hydrogen Cost at Station in a range of 2,75 – 3,50 USD/kg (USD/GGE). In U.S. market the assumption for the cost of the natural gas and electricity, specifically whether industrial rates or commercial rates were applicable, is

Table 4 - Estimated H2FC Powertrain Levelised Cost of Electricity

H2FC Powertrain Efficiency	H2FC Powertrain Hours LIFE	Hydrogen Cost USD/GGE°	Capital Overnight OVN Cost (USD/kW)^	Levelized Capital Cost LCC (USD/MWh)	O&M + Others (Assumed Equal to 10% LCC, USD/MWh)	Fuel Cost (USD/MWh)	Levelized Cost of Electricity LCOE (USD/MWh)	
53%	**2500**	**3,0**	**61**	24,4	2,4	169,8	**196,7**	2009 DOE status
59%	**2500**	**3,0**	**61**	24,4	2,4	152,5	**179,4**	2009 DOE status
53%	**2521**	**3,0**	**61**	24,2	2,4	169,8	**196,4**	2009 DOE status
59%	**2521**	**3,0**	**61**	24,2	2,4	152,5	**179,2**	2009 DOE status
60%	**5000**	**3,0**	**30**	6,0	0,6	150,0	**156,6**	2015 DOE targets
60%	**5000**	**2,0**	**30**	6,0	0,6	100,0	**106,6**	2015 DOE targets

^ Projected, high-volume manufacturing cost of automotive H2FC systems
° Distributed Natural Gas Reforming status and targets assume station capacities of 1500 kg/day, with 500 stations built per year

not clear cut. In this sense, in order to reduce the distributed natural gas reformation Hydrogen price, is fundamental to reach 500 new delivery stations per year and, in this way, obtain the industrial gas price rate, much lower than the commercial gas rate, and consequently reduce the Hydrogen production costs.

3.2.2 The 2015 Targets

Based on the same projected high volume assumption, we adopt the U.S. DOE technical targets (Reference [16]) for year 2015: Overnight cost 30 USD/kW, Levelized Capital cost 6 USD/MWh, Lifetime 5000 hours, 60% System Efficiency, and 2 - 3 UDS/GGE Hydrogen cost.

Considering high H2FC Powertrain stress connects with transportation application, the expected lifetime system in stationary application should be much higher than 5000 hours, nevertheless, in our analyses, we consider only U.S. DOE targets.

According to Reference [13], the lower value of the Hydrogen cost range (2 UDS/GGE) is referred to coal gasification with CO2 sequestration Hydrogen production.

3.2.3 Other Consideration and Assumption

Thanks to the fact that the expected system life is shorter than one year (also in 2015), it is not necessary to consider any financial aspect.

With regards of Operations and Maintenance (O&M) and Other costs, we assumed these costs as equal to 10% of Levelized Capital Cost.

Considering the fact that H2FC Powertrain is a completely new technology in our analysis we compare our H2FC powertrain LCOE data with the high-discount rate analyses data (when available).

Even if we have in mind H2FC Powertrain thermal management issues and also the possibility, if the H2FC Powertrain system will be specially equipped for that, to recover the heat co-produced during the electricity generation (like in a CHP power plant), our simply and preliminary analysis do not take in consideration these aspects. In addition, we do not considering any possible cost related to the vehicle-to-grid electrical connection outlet.

3.2.4 Results

For 2009 we find the LCOE H2FC Powertrain value in a range of 179,2 -196,7 USD/MWh.

For year 2015, we find the LCOE H2FC Powertrain value in a range of 106,6-156,6 USD/MWh.

Table 4 shows our estimated H2FC Powertrain LCOE.

4. Conclusion

Based only on public data, H2FC Powertrain is considered as power generation plant and the cost of electricity production is compared with the generation costs of the traditional power generation technologies in a simple and preliminary analysis.

Using only 2009 tested U.S. DOE H2FC Powertrain data (referred to high projected production volume) we found that the cost generating baseload electricity (LCOE) would be in a range of USD 179,2 -196,7 for MWh.

Comparing this cost range with the LCOE published in the most recent studies, we observe that H2FC Powertrain generation would be at lower cost than wind offshore, solar thermal and solar photovoltaic.

Using the 2015 U.S. DOE data target the of H2FC Powertrain the LCOE electricity production cost range moves to USD 106,6-156,6 for MWh, and, in most of the context, it appears competitive with all the power generation technologies.

These preliminary results suggest that further investigation is needed.

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